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Level-Basin Irrigation

A Method For Conserving Water And Labor

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Level-Basin Irrigation: A Method for Conserving Water and Labor

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INTRODUCTION

Level-basin irrigation, a gravity method whereby water is supplied to level soil surfaces over a short period of time, is assuming increasing importance to U.S. agriculture as a conservation tool. At a time of increasing irrigation needs and concern over energy and water supplies and high labor costs, the method is being used extensively in the Southwest to improve water application efficiency.

Level-basin (or dead level) irrigation (fig. 1) involves applying water to a level ground area of any shape surrounded by a control barrier such as a dike. Level basins differ from commonly used graded border irrigation. Graded borders have slope in the direction of irrigation. The water, applied to the basins over a short period of time, is confined until absorbed by the soil.

Design of basin size depends upon water supply flow rate and soil infiltration characteristics. Level-basin irrigation can be adapted to all crops, soils, and to certain marginal-quality water not usable in other methods of irrigation. It is best adapted, however, to low to medium water-intake-rate soils.

Level basins have been used for centuries, especially for rice production in Italy and Russia, but the practice is relatively new in Western United States. It is now in operation on some 40,000 to 50,000 acres of field crop production in the Wellton-Mohawk Valley near Yuma, Ariz. The use of level-basin irrigation is rapidly expanding to other parts of Arizona and southern California.

ADVANTAGES

Level-basin irrigation systems have many characteristics which can result in high irrigation efficiency as well as offer other advantages over other more commonly used surface irrigation techniques. Advantages of level-basin systems are as follows:

- If the system is properly designed, deep percolation losses are

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Figure 1—Eight- to 9-acre level basins irrigated from single turnouts located at corner of each basin. Irrigation is complete on upper two basins; third basin is being irrigated. Water is brought to basins in concrete-lined ditch.

minimized and high water application efficiencies (the ratio of water required for an irrigation and amount of water applied) are attained since no water runs off (no tailwater). Application efficiencies above 90 percent are commonly attained on fine-textured (low-intake) soils. Irrigation efficiencies will be lower for coarse-textured (higher intake) soils. The key to attaining high efficiency is to get water over the entire field as rapidly as possible so that the difference in infiltration opportunity time is small for all areas of the basin.

• Leaching of salts is accomplished naturally with a level-basin irrigation system. The reason for this is that since water uniformly covers and remains static over the entire surface, it has the opportunity to penetrate evenly, reducing residual salts that normally remain with sloping types of furrow or border irrigation. Since rainfall will not run off, it, too, may be useful for leaching purposes.

• Deep percolation water will be minimal on a properly designed and managed level basin. This reduces water table buildup and minimizes drainage requirements. Precise water application also maintains fertilizers in the root zone and minimizes the degrading effect of these fertilizers in the ground water.

• The guesswork in applying the right amount of water is eliminated since there is no surface runoff and all water applied to a basin is used within that basin. The formula

$$T = \frac{AD}{Q}$$

can be used to calculate the time of set T (hours) since the area A (acres), can be measured; the depth of water to be applied, D (inches), is a known quantity; and the flow Q in cubic feet per second can be measured. Some allowance for deep percolation losses may need to be made when applying the formula. Thus, the main obligation of the irrigator is to change the water from basin to basin at predetermined times.

• Relatively light applications of water are possible. Success is dependent upon proper design—balancing flow rate with size of the field and water intake characteristics of the soil. This advantage is especially desirable for vegetable crops, fertilizer application, frost control, and germination.

• Automation can be conveniently applied to this method of irrigation for the following reasons: (1) The time of set can be controlled directly with clocks; (2) only a few outlet structures are needed; and (3) no tail water exists for further handling.

• Furrows, as well as flatbed crops, are well adapted to this method of irrigation since the same elevation of water will be attained on all parts of the field. Since all furrows are connected at both ends of the field by a secondary ditch, differences in rates of advance between rows are of minor importance. Furthermore, crops grown using furrows can be germinated evenly by maintaining a uniform water depth throughout the field, thus minimizing inundation and soil crusting over seedbeds.

• Large streams of water can be used with level-basin irrigation, thereby reducing irrigation time. Changing irrigation sets on a predetermined time schedule eliminates the need for continual attention by the irrigator. Regardless of the stream size, single or multiple outlets which require little time to open or close can be used to turn water into a field. These factors result in low labor requirements.

• If single outlets are used at the corners of the fields nearest the water supply, a supply ditch is not needed along the edge of the last two basins. Less ditch means reduced waste area and reduced costs and maintenance.

• Level-basin fields as large as 40 acres may be efficiently irrigated where a large stream of water is available and the water intake of the soil is low. Fields this large are void of waste area and can be easily farmed with large machinery.

• All rainfall will be confined within the diked area for plant growth and leaching. Unlike sloping irrigated land, there will be no erosion from rainfall because the area is flat.

• Increased yields will result with level-basin irrigation systems because the exact amount of water necessary for plant growth can be evenly distributed to all parts of the field. Even distribution results in improved germination, improved plant environment, even growth, and, ultimately, improved production.

LIMITATIONS

Although level-basin irrigation has many advantages over other irrigation methods, the following limiting factors should be considered.

- Precision leveling may be difficult, but it is necessary for even water distribution. After the total amount of water has been applied, the standing water is allowed to penetrate. If low or high areas exist, uneven penetration will occur and uniformity of application, an advantage of level-basin irrigation, will be reduced. With the recent commercial availability of laser-controlled land leveling equipment, many limitations associated with precise leveling requirements have been eliminated.

- As with all methods of irrigation, the correct amount of water must be applied. This requirement is perhaps more important for the level-basin method because over-application may lead to excessive inundation times and result in crop damage. Salt problems may result from misapplication of water.

- More soil movement will generally be necessary when leveling land for level-basin irrigation than for other types of surface-irrigation systems. The amount of land leveling is limited by the depth of topsoil, but where well-developed topsoils exist, the amount of soil movement will likely be controlled by leveling costs. Variable soils within a basin may create water distribution problems and efforts to eliminate these variations will probably be required.

- Costs of developing land for level-basin irrigation depend on the size of the basins and the topography of the land. From an irrigation design standpoint, basin size is dependent on the flow rate and intake characteristics of the soil. Large flows may result in large basins with fewer turnout structures and associated equipment, but large basins may mean excessive earth moving if the topography is not relatively level. Hence, topography rather than stream size may be the limiting factor.

- A large stream is desirable to achieve best results with level-basin irrigation, but elaborate erosion preventive structures will probably be required. As a way of reducing erosion, the number of outlets can be increased, but this eliminates some advantages of level-basin irrigation.

- Level-basin fields that are benched are susceptible to dike breakage if too much water is received. Furthermore, long inundation times may cause crop damage. Hence, a means of emergency drainage should be provided when using level basins to protect against irrigator's error (overirrigation) and especially in areas where large amounts of rainfall might occur in a short time.

- Secondary ditches along the edges of a basin will generally be required to distribute water into bed or row crops. Temporary dikes may also be required to prevent overtopping of beds directly in front of the turnout.

LAND PREPARATION

Since there is no runoff water with level-basin irrigation systems, the only inefficiency occurs in the distribution of water within a field. As with other surface methods of irrigation, irregularities in soil infiltration rates and land elevations result in uneven distribution.

Topsoils should be as similar as possible within a basin to assure uniform water distribution due to intake. If the soil is not uniform over the entire area, the following measures can be taken to correct this situation:

1. For broad soil variability across a field, select basin size and shape to provide similar soils within a basin.
2. For spotted soil variability within a basin, undercut dissimilar streaks of soil occurring within a basin and replace with soil similar to the rest of the basin.
3. For irregularity of soil within a root zone (lenses dissimilar from most of profile), deep plow soil profile to mix soil.

Land grading must be accurate for successful level-basin irrigation. The principle of level-basin irrigation is to allow all parts of the field to receive water for equal lengths of time. Equal infiltration cannot be effectively accomplished, however, if low and high spots exist. In addition to unequal distribution, low spots are subject to excessive inundation and high spots may become salty and dry out prematurely.

Originally, fields to be leveled were first surveyed, the cuts and fills calculated, and the information transferred to the stakes. Soil was then moved to comply with the survey, and leveling equipment controlled wholly by the operator was used to level the land. Even though great care was taken, the precision attained was generally related to the ability of the operator. Figure 2 represents the topography of a conventionally leveled field considered to be well leveled. Note some parts of the field will receive about 5 inches more water than other parts of the field.

Early in 1975 the first laser-controlled scrapers used for final finishing were introduced in the Wellton-Mohawk Valley in southwestern Arizona (fig. 3). This equipment facilitates leveling to less than 1 inch from high to low for areas as large as 40 acres. It can also be used in leveling to a particular graded slope. In addition, laser-controlled equipment significantly improves water distribution uniformity and eliminates much of the need for surveying and staking and using other outdated leveling practices. Precise leveling, by eliminating high spots, can reduce the gross quantity of water applied by at least 20 percent.

BASIC PRINCIPLES AND DESIGN

In a level-basin irrigation system, water first moves over the basin and then becomes static. The amount of water that would be infiltrated is related to both the time of water advance across a field and the time

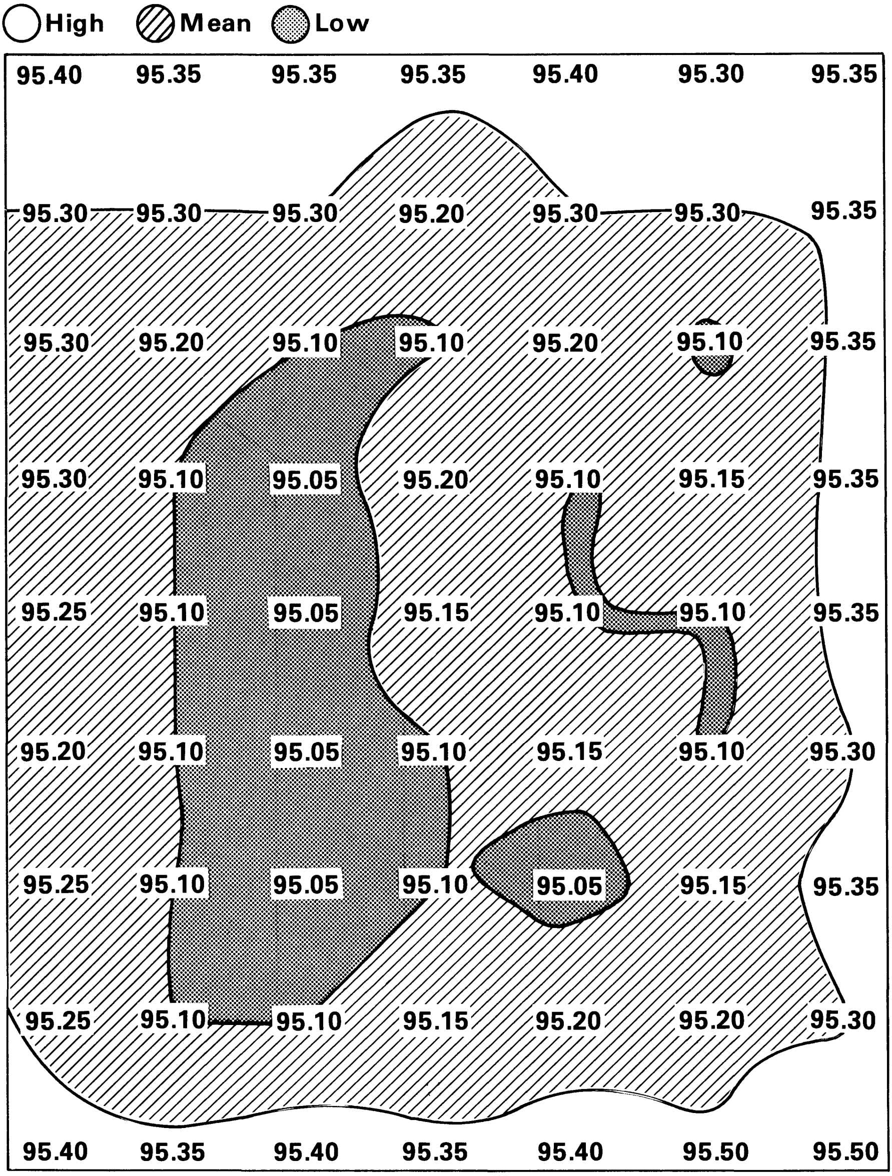

Figure 2—Typical topography of conventionally leveled field before laser leveling. Much of the area around edges of this approximately 11-acre basin is higher than rest of basin, a common occurrence with conventional equipment. Yields and crop stands reflect water distribution, that is, over-irrigated low areas are weedy and high areas, droughty and low-producing.

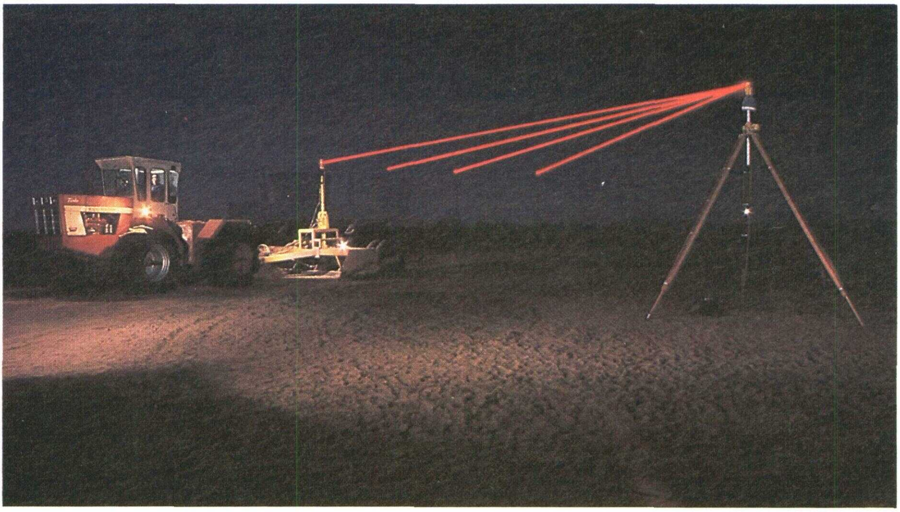

Figure 3—Dragscraper in background controlled by laser on tripod in foreground precisely levels land for level-basin irrigation. Equipment has provided degree of precision needed to distribute water uniformly over level basins.

that the water sets (static) on the basin.

The system should be designed so that allowable distribution error is met by restricting the size and shape of the basin. Four factors must be considered in system design: (1) Water intake characteristics of the soil; (2) available flow rate; (3) resistance to flow caused by the crops to be grown; and (4) the quantity of water to be applied. With this information the designer can determine the length and width of the basin to attain an allowable water distribution difference.

In designing some basins, the water depth buildup associated with crop resistance to flow may be a limiting factor and will be used to establish the basin configuration. In addition, the size and shape of basins may be controlled by factors such as section lines, streams, topography, high lines, soil depth, ownership, roads, soil type, crops, and farmsteads. However, size and shape must be within design limitations.

Current design of many level basins is based on the performance of previously constructed systems which used the same or similar types of soil and cropping and water requirements. A useful guide for designing level-basin systems in new areas was published in 1974 by the Department's Soil Conservation Service entitled, "National Engineering Handbook: Irrigation." Section 15, chapter 4 on border irrigation, is of special interest. Copies of this publication are offered for sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20401.

Advantages of evaluating a level-basin system operation are (1) providing the designer or irrigator with a means of closely checking the system and what changes, if any, may be desirable and (2) serving as a guide for the application of irrigation water, either with a system based on design estimations or on the performance of previously constructed systems. Specific information needed to evaluate a level-basin system operation follows and is illustrated with actual field data.

Field Trial 1

• *Flow rate:* Measured with flume or other appropriate device to within accuracy desired. The flow rate was 15 cubic feet per second for the field studied.

• *Water application time:* Calculated by using the formula

$$T = \frac{AD}{Q}$$

(see p. 5). This will be the time needed to apply an average depth, D (in the example, 4 in), of water to the basin area, A (9 acres), at the measured flow rate, Q of 15 cubic feet per second. For the example presented, the application time was 2 hours, 24 minutes.

• *Rate of advance:* The rate at which water moves over the soil surface. For detailed analyses, a time record should be made of the location of the water front as it progresses over a basin. Such a record is shown in figure 4. The study was made on an approximately square field of knee-high alfalfa, using a 15 cubic feet per second flow rate turned out of one corner. These data were then used to plot an advance curve (fig. 5). The advance curve is a line which plots the time after water was turned in versus the distance water has advanced or portion of a field covered at that particular time. Figure 5 depicts the advance results of the corner turnout and, therefore, a portion of field covered is used in the figure. For this study the entire basin was inundated in 2.1 hours.

• *Recession time:* Difference in time from when water was turned on to when it disappears from a certain portion of the soil surface. For all practical purposes the recession time for a level basin is the same for all locations within the basin. For the example the recession time was about 18.5 hours.

• *Cumulative intake:* Depth of water infiltrated into the soil with respect to time. Cylinder infiltrometers are generally used on level basins to obtain the required intake data. The average cumulative intake curve for the field studied (average of 3 cylinders) is shown as figure 6. Note the rapid intake of water (nearly 1.7 in) by the soil during the first 2 hours. Thereafter, the intake was nearly constant at 0.15 inch per hour, referred to as final intake rate.

• *Soil moisture conditions:* Should either be measured or estimated at the time of irrigation.

• *Distribution efficiency evaluation:* The actual amount of water

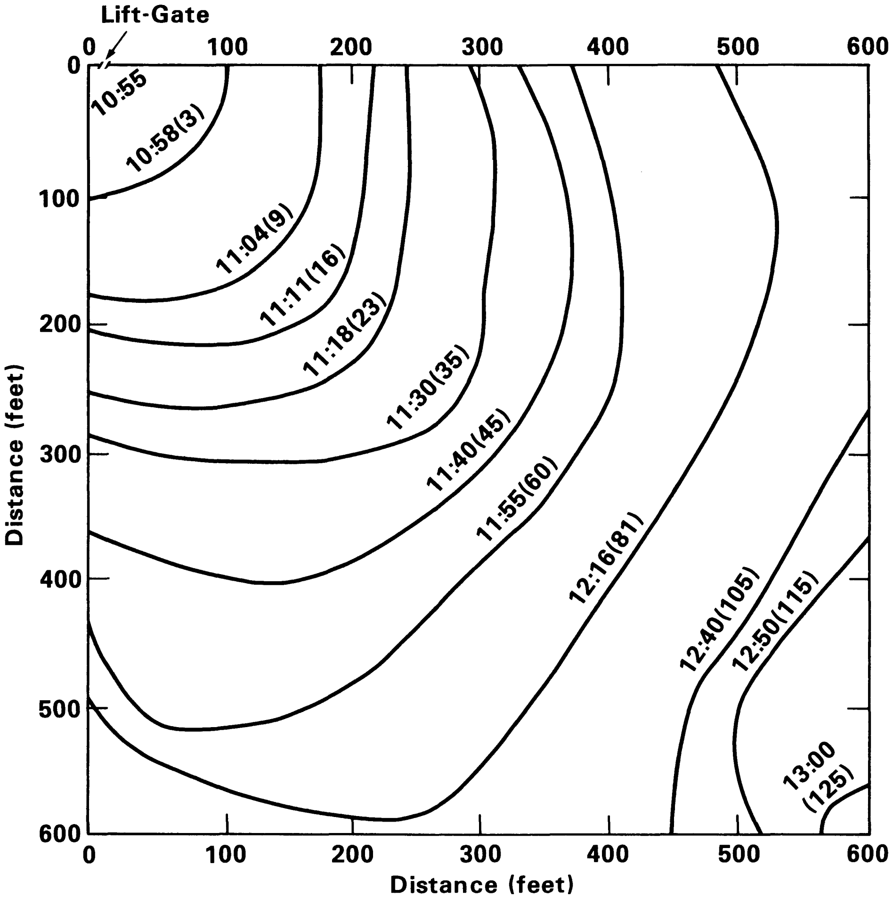

Figure 4—Water advance contours on a level basin. A stream of water flowing at 15 cubic feet per second was turned into basin at upper left corner. Lines represent location of water on 8-1/4-acre basin.

that is infiltrated into the soil depends on the infiltration opportunity time. The opportunity time is the difference in the recession time and the water advance time for the particular portion of the field being considered. Water advance times for various percentages of field coverages are given in table 1, column 2 (also see fig. 5). The infiltration opportunity time (col. 3) for the various portions of the field were calculated (that is, infiltration opportunity time at the 40 percent coverage point was 18.5 hours minus 0.8 hour, or 17.7 hours). The amount of infiltrated water was then read directly from the cumulative intake curve of figure 6 and recorded for the various opportunity times (col. 4).

The difference in water infiltrated

from one end of the field to the other was 0.32 inch. Distribution efficiency is calculated as:

$$E_d = \frac{\text{minimum depth infiltrated}}{\text{average depth infiltrated}} \text{ X } 100$$

or

$$E_d = \frac{3.85}{4.00} \text{ X } 100$$

$$E_d = 96.3 \text{ percent}$$

The distribution efficiency indicates the degree of underirrigation at the point receiving water last. If the irrigator wants to apply at least a 4-inch irrigation to this far point, then the gross application should be increased by about 4 percent (100 minus 96.3 pct). Distribution efficiencies would be higher for larger applications and lower for smaller irrigations on the same basin. A large portion of the field is within 0.05 inch of the mean application of 4 inches. Obviously this is a good, efficient field design and the size of the stream fits the infiltration characteristics of the soil.

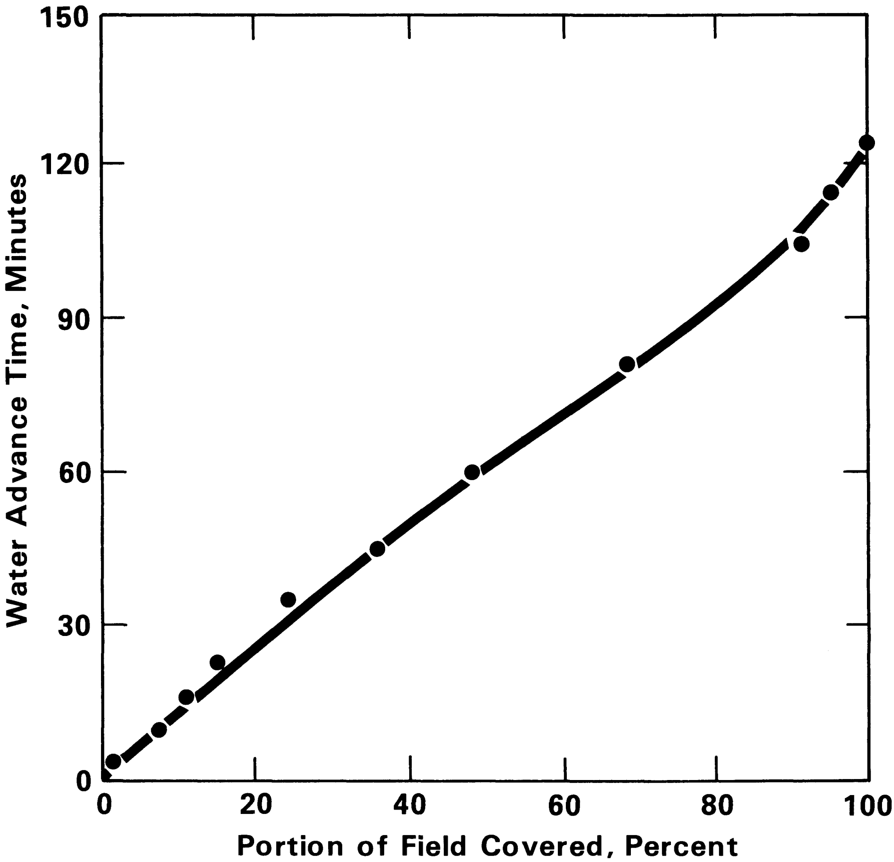

Figure 5—Time rate of water advance over field. This is graphical representation of data illustrated in figure 4.

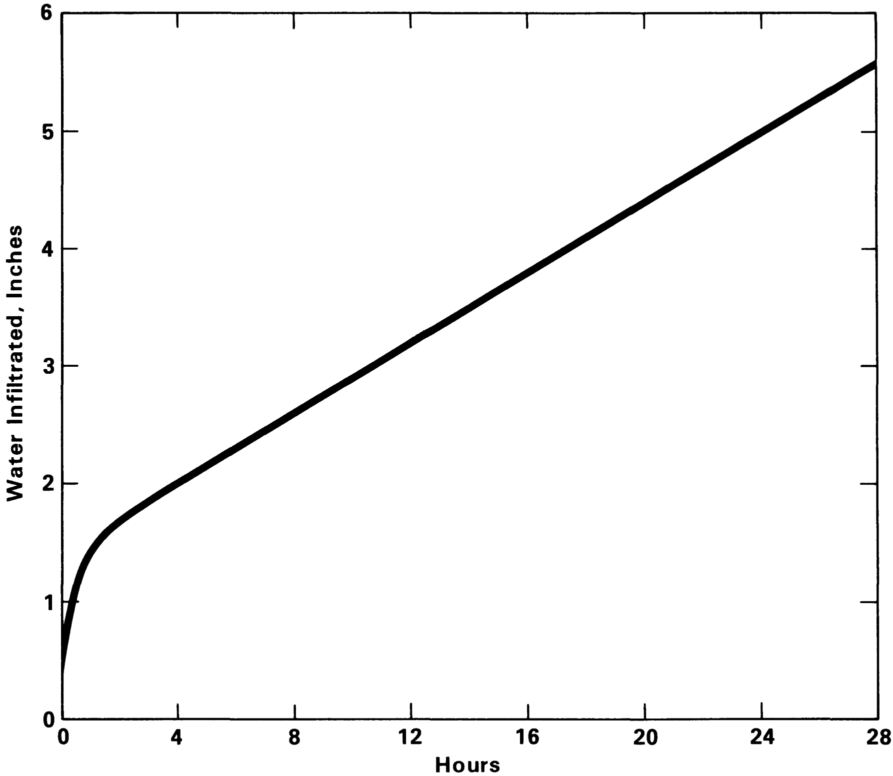

Figure 6—Cumulative amount of water infiltrated into soil, related to time as determined by use of cylinder infiltrometers.

Field Trial 2

Another study was conducted on an adjoining 1,240-foot basin having a 330-foot frontage. Water, at 15 cubic feet per second, was turned out through three 16-inch concrete pipes at the narrow end of the basin. Wheat was about 15 inches high and densely planted. A small furrow along each border dike assisted in moving the water to the end of the basin faster along the edges than through the middle of the basin. Water was applied for 3 hours 15 minutes, which represented an average application of 5.2 inches of water to the basin. Recession time was about 27 hours.

Since the cumulative intake function was similar to that found for the first field study, data in figure 6 were used as a basis for values presented in table 2. Water advance times for various portions of the basin shown in table 2 represent the infiltration opportunity times and infiltrated water for each location along the basin. It took 4.3 hours for the water to cover the field compared to 2.1 hours for the square field studied earlier. The distribution efficiency is:

$$E_d = \frac{4.80}{5.20} \times 100$$

$$E_d = 92.3 \text{ percent}$$

The far end of the field was under-irrigated by 0.40 inch and the variation from end to end was 0.64 inch.

These figures are tolerance figures, which the farmer or designer, or both, could use in making decisions on the size and shape of the field. Possible advantages of a longer field are one less supply ditch, with its supporting structures, more convenient farm operations, and less nonproductive land. Generally, longer basins, given the conditions illustrated here, would be advantageous when differences in infiltration are so small.

TABLE 1.—Water advance time and infiltration for various portions of the basin, Field Trial 1

Portion of field covered (percent)	Water advance time	Infiltration opportunity time	Infiltrated water
	Minutes	*Hours*	*Inches*
0	0	18.5	4.17
20	24	18.1	4.09
40	48	17.7	4.02
60	72	17.3	3.99
80	90	17.0	3.94
100	126	16.4	3.85

TABLE 2.—Water advance time and infiltration at various locations within the basins, Field Trial 2

Distance from water inlet (feet)	Water advance time	Infiltration opportunity time	Infiltrated water
	Hours	*Hours*	*Inches*
0	0	27.0	5.44
200	.5	26.5	5.37
400	.9	26.1	5.31
600	1.4	25.6	5.23
800	2.1	24.9	5.13
1,000	2.9	24.1	5.01
1,200	4.1	22.9	4.83
1,240	4.3	22.7	4.80

GATES AND OUTLET STRUCTURES

Many types of gates are used to turn water into level basins from either open ditches or underground pipes. The ease by which these gates can be operated is important. When water is distributed through concrete-lined canals, it can be turned into the basins from single or multiple outlets.

Single outlets are generally equipped with lift gates (fig. 7), while multiple outlets are usually equipped with slide-type gates (fig. 8). If water is distributed to the basins in underground pipes, caps are used on the end of a pipe rising from the mainline to the field surface to control turnout through either single or multiple turnouts (fig. 9).

The decision to use single or multiple turnouts is generally related to comparative costs and owner's personal choice. Some structures, however, are better adapted for row-crop irrigation than others, and some require less elaborate erosion preventive measures. Distribution of the water into rows or beds can be adequately accomplished, however, with various types of secondary ditches regardless of the number of turnouts (see section on "Cultural Practices," p.18).

Lift gates require only one maneuver and a minimum of labor to turn the entire stream into a basin or to cut it off. These gates can also be designed into a system so that four gates can be located within a few feet of each other and still irrigate four separate fields from adjacent corners. Distribution from basin

Figure 7—Type of lift gate commonly used to turn water into level basins. Little time is required in opening and closing gates like this when changing water from basin to basin.

Figure 8—Slide-type gate mounted on inside of concrete-lined canal over end of concrete pipe leading to level basin. More than one gate is required per basin when flow rate is above 4 or 5 cubic feet per second.

corners can eliminate the supply ditch along the edge of the last basins at the end of the farm ditch saving considerable costs. Single outlets at the corners can be conveniently automated. As a result of its corner location, the supporting erosion preventive structure is protected from breakage by machinery.

Scoured areas or potholes may occur where the water is turned into the basin. To prevent this type of erosion, a structure associated with the gate should be selected that creates a low velocity discharge rate or dissipates the energy of the water before reaching the soil surface. Several typical erosion preventive structures are shown in figures 10 and 11. A single turnout requires only one structure per basin, but the structure will be more elaborate than those used for the smaller stream multiple outlets.

Figure 9—Alfalfa-type valve usually used to turn water onto level basin from underground pipe distribution system.

Figure 10—Erosion structure designed to dissipate energy resulting from large flow rates (15 to 20 ft ^{3}/s) through lift gates. Success of structure is based on level concrete block sill which ponds water causing even flow over sill. Water then flows onto concrete apron in foreground, extending about 3 feet beyond sill and slightly below finished field elevation.

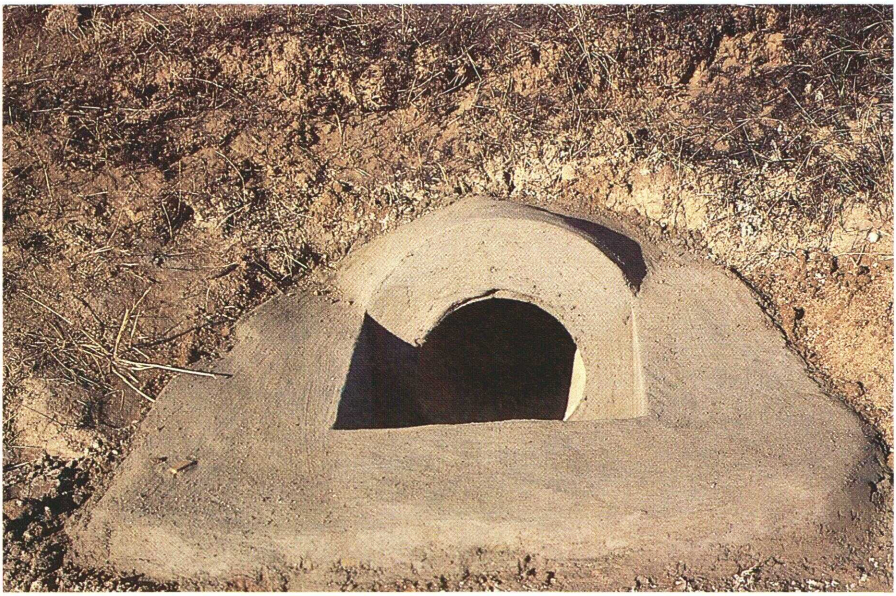

Figure 11—Small erosion control structure at outlet end of 16-inch concrete pipe through which water flows from supply ditch to basin. Maximum flow rates expected through turnout would be 3 to 4 cubic feet per second.

CULTURAL PRACTICES

Normally, close-growing crops, such as alfalfa, hay, pasture and small grains, are simply flood-irrigated and the level-basin facet takes care of the distribution. Row crops such as cotton, sorghum, safflower, and corn may be planted and irrigated on the flat with level basins; then, only minimum effort is needed to attain even distribution of water. There are probably several crops, including vegetables, that could be produced on the flat, but cultural and management practices have not yet been developed.

Some irrigated farming practices usually used may not be needed after the land has been converted to level-basin systems. However, to properly distribute water into basins with row or bed crops special practices are generally needed. These practices are discussed in the following paragraphs.

Installing spiles or syphon tubes from a secondary ditch to individual furrows (as in sloping-surface irrigation) is not necessary for level-basin systems. Since all parts of a level basin are at the same elevation, water will always cover all parts of the field. Water will move faster along some furrows than others but upon reaching the end will turn and come back in a slower advancing furrow (fig. 12). The net result is improved uniformity of application.

When large streams are diverted through single turnouts into basins with row or bed crops, the onrush-

Figure 12—Water being distributed to field by multiple outlets in background. Water enters furrows at different rates and quantities. Furrows with rapidly advancing water reach lower end, turn and meet slower advancing furrows.

ing water will overtop and erode the rows or beds in the immediate vicinity of the turnout. To prevent this overtopping, the stream usually must be split or diverted. Where multiple outlets are used, erosion and overtopping are minimized but not likely eliminated. Temporary control checks between turnouts at both the near and far end of the field at identical intervals can be used to better distribute the water (fig. 13).

The stream can be split or diverted by utilizing a wide, secondary distribution ditch constructed perpendicular to the direction of irrigation (fig. 14). When large streams are used, the width of the ditch should generally be no less than 10 feet wide so that the water is nonerosive. The width selected must be easily constructed with available equipment. The ditches are generally flat bottomed but, if possible, should be tilted with deeper edge away from the field (fig. 15). Tilting away from the field helps to maintain a constant water elevation and flow into the field, especially during the initial part of the irrigation. Tilting toward the field should be avoided.

An additional modification of a corner turnout is to split the stream

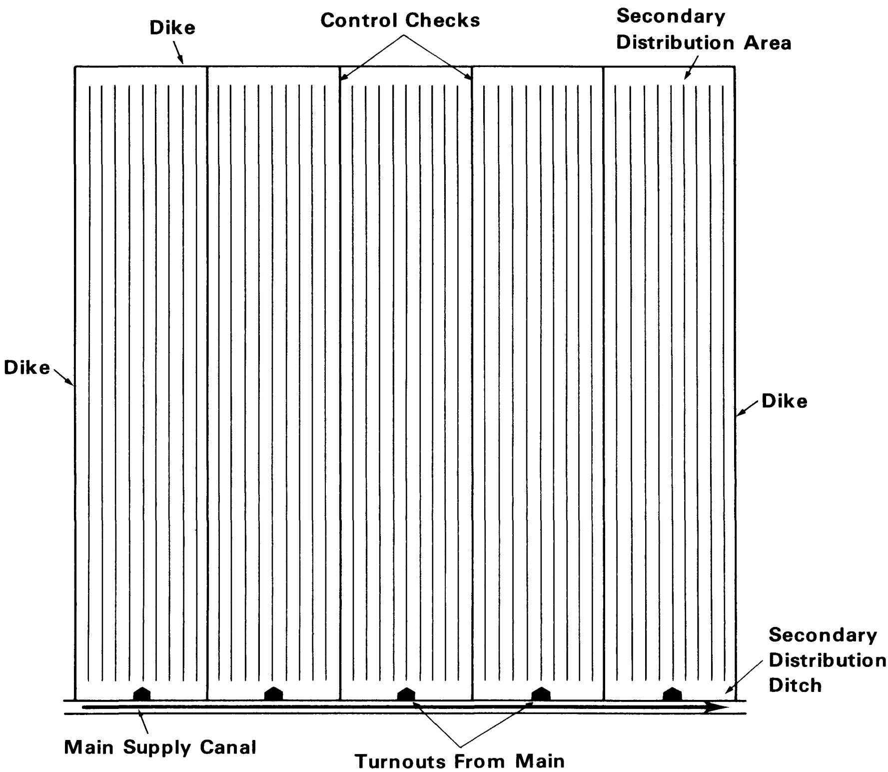

Figure 13—Field plan utilizing multiple outlets with temporary control checks. Soil checks facilitate equal distribution of water from several turnouts, thereby minimizing erosion.

of water close to a corner turnout and to take part of the flow into a small, temporary ditch along the side of the field and across the far end in another secondary distribution ditch while the rest is distributed across the turnout end (fig. 14).

Another modification of a single turnout is to construct a temporary ditch down the middle of the basin or any critical place so that water can be carried to the far end of the field and then across the end in other secondary ditches, the location depending on row or bed direction

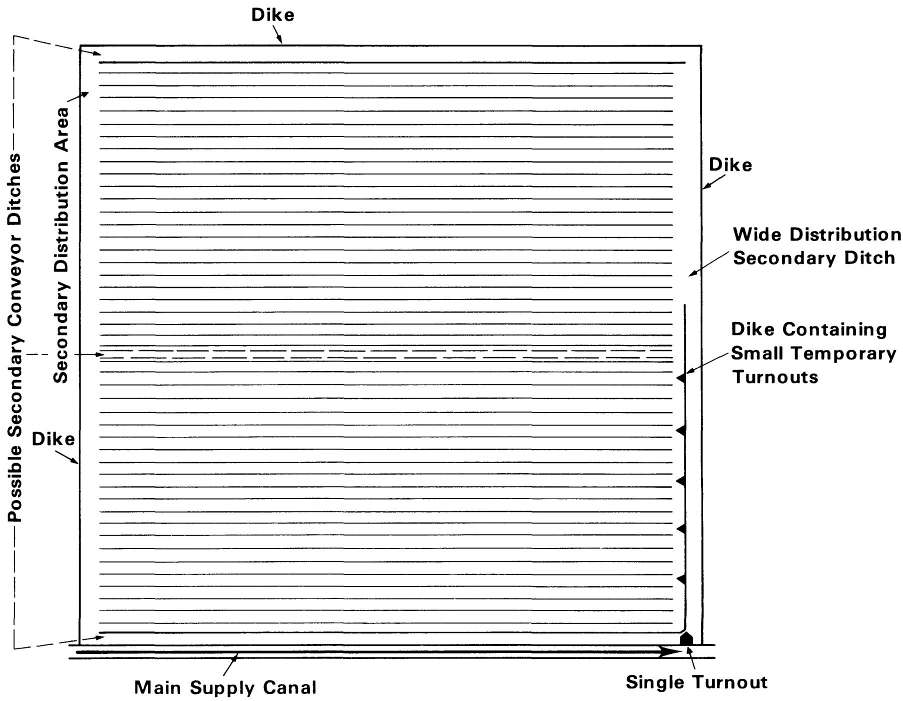

Figure 14—Field plan for row or bed irrigation to minimize erosion when single turnout is used. Suggested locations show possible use of secondary conveyor ditches which may be used.

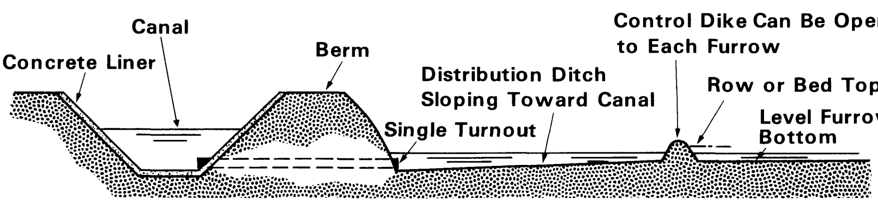

Figure 15—Cross-section of canal and field showing distribution ditch, usually no less than 10-feet wide, which assists in maintaining constant elevation of water along inlet end of rows, thereby helping to control erosion. Distribution ditch should never slope toward field.

(figs. 16 and 17). Splitting the stream of water and getting it to the far end of the basin more quickly is especially important on higher intake rate soils. Each farm should use modifications that best fit its special need. If every-other-row irrigation is desired, furrows not to be irrigated can be blocked at both ends of the field.

The water within a level-basin area is controlled by the basin's outer edges, which normally consist of a supply ditch along one side and then by roads or border dikes on the other three sides. As with all methods of irrigation, all borders should be maintained because of soil cracking and damage from rodents. Because of soil cracking on many clay-type soils, disking and remaking the dikes may be necessary before each irrigation.

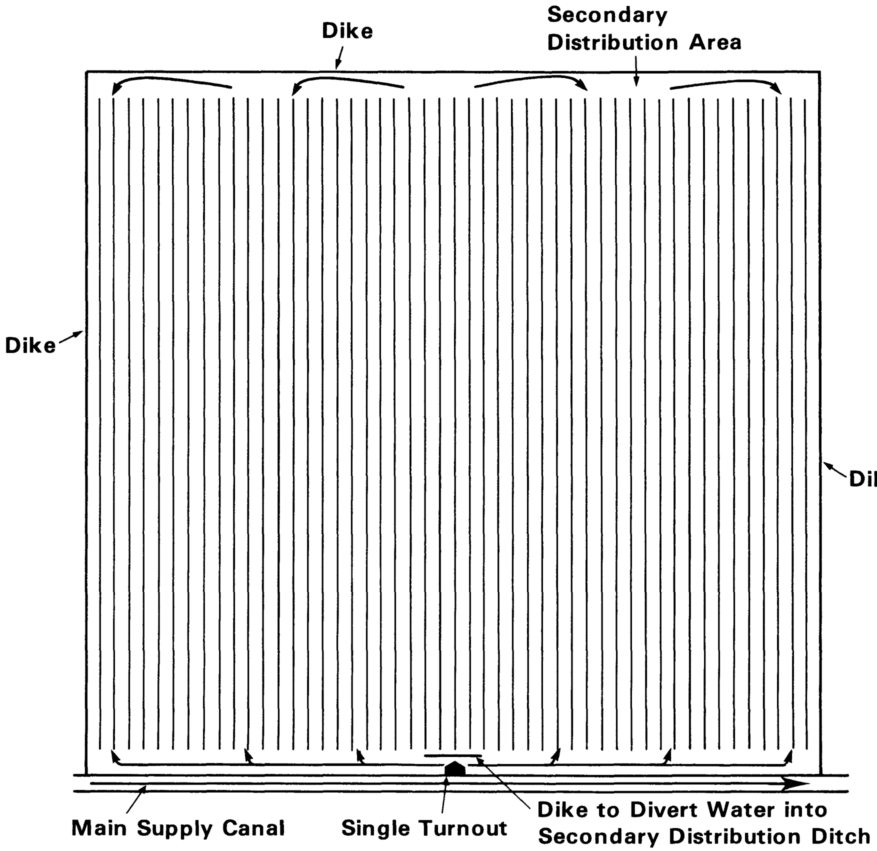

Figure 16—Field plan for single, middle-of-the-field turnout with rows or beds perpendicular to main canal. Temporary dike must be constructed in front of turnout to protect rows directly in front of turnout from eroding and overtopping. Dike is often protected with sheet of plastic.

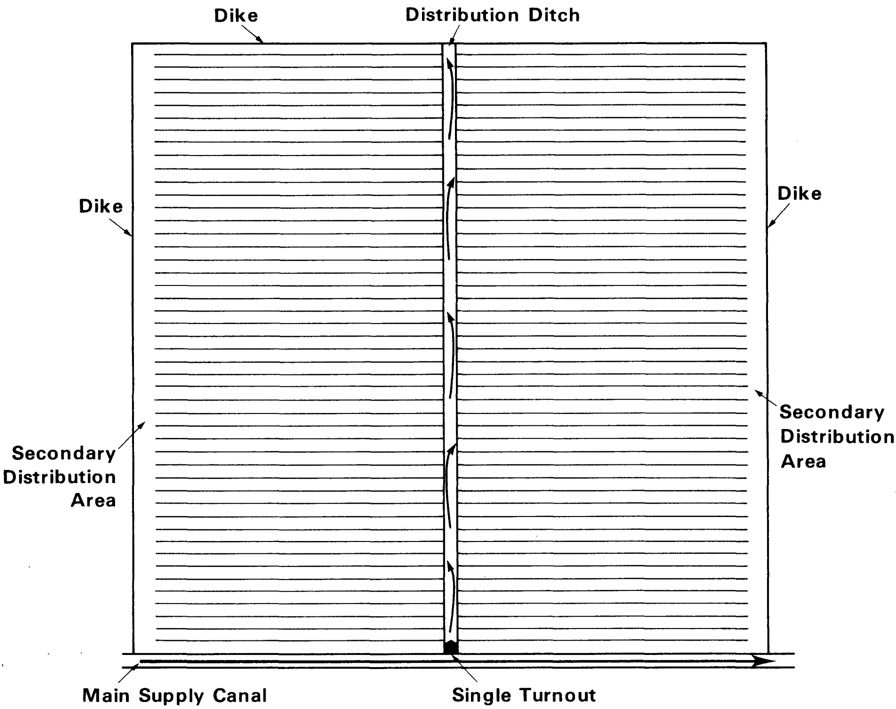

Figure 17—Field plan for single, middle-of-the-field turnout when running rows parallel to main canal.

MANAGEMENT

As with all irrigation methods, a perfectly designed and adapted irrigation system is no remedy for poor management. Success is related to proper management. The questions of when and how much water to apply must be answered for all methods. How to apply water to a level basin centers around the ease of controlling and distributing the required amount. Water turned into the basin will level out and cover all parts of the basin. Factors to be considered are basin acreage, flow rate, desired depth of application, and an allowable distribution difference.

Basin area (actual cropped area) can be determined from direct measurement. Flow rate available to a basin must and can be accurately measured. The quantity of water to apply can be determined from crop requirements or evapotranspiration projections and the water-holding characteristics and residual moisture levels in the soil. The water distribution difference from one end of the field to the other can be estimated from available design

information or actual system evaluation (length-of-run and intake measurements). Once these management requirements are met for level-basin irrigation, it is then only a matter of irrigating each basin for a certain calculated period of time.

In level-basin irrigation, water applied to a basin will remain until it penetrates into the soil or evaporates. In some areas and with some plants, the manager must be careful not to let the water stand too long. How long a plant can be inundated varies principally with temperature, type of plant, and growth status. Thus, applying the proper quantity of water is paramount. Alfalfa, corn, safflower, and many vegetables are sensitive to excessive inundation.

Inundating seeds is undesirable during germination. The irrigator of a level basin should apply only enough water to approach the seed line and maintain that elevation until water and salts have moved past the seed area. To do this the stream flow is reduced until it equals the intake rate, thus maintaining a constant water level.

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